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Tactile Spatial Ability: Lateralized Performance of Deaf and Hearing Age Groups

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Hearing adults, 8- and 6-year-old children, together with deaf 9-year-old children, were tested on a unimodal haptic matching task. One additional group of adults was tested with a shorter stimulus presentation time. Data indicated that left-hand superiority was most evident in the performances of the older hearing children, and of the adults with the shorter presentation time. Hemispheric specialization was less noticeable for the younger hearing group, but the task may have been too difficult. A slight right-hand superiority was found in the performance of adults with long presentation time. This may reflect the simplicity of the task for these subjects. Deaf children did not show any clear hand differences, but were superior in overall performance to hearing children.

The aim of the present study was to investigate the development of lateralization of cerebral function for touch. A subsidiary aim was to assess whether deaf children, because of their restricted range of sensory input, showed any deviations from normals in their lateralization pattern for this sensory system. To this end the procedures described by Galin, Johnstone, Nakell, and Herron (1979), and Flanery and Balling (1979) were combined in order to mesh together the best features of both. Galin et al. (1979) reported increased ability with increasing age on a task requiring interhemispheric transfer of tactile information. Their subject's task was to decide whether two fabric pieces, presented sequentially both to one hand or one to each hand, were of the same or different textures. Three- and five-year-old children made approximately the same number of uncrossed errors; there was no difference between crossed and uncrossed errors for the 5-year-olds, but 3-year-olds made significantly more crossed errors than uncrossed errors. With respect to left–right hand comparisons, there was no significant difference in un-

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crossed errors for either age group, but crossing from right to left produced more errors than crossing from left to right. Galin et al. (1979) did not offer an explanation for the latter effect. However, it is conceivable that textural information may be more efficiently processed by one hemisphere, which would lead to the reported left–right differences. One of the problems associated with the task used by these authors is that no time constraints were imposed. Thus, there was no limit on the amount of time available for interhemispheric transfer of information.

In another study of the development of tactile ability Flanery and Balling (1979) followed up, and extended, Witelson's (1974, 1976) original findings. Using her dichhaptic task with random shapes, single-hand exploratory procedures were employed with half the subjects, and dichhaptic procedures with the other half. In the single-hand condition, a single stimulus shape and the test or comparison shape were successively presented to one hand. In the dichhaptic condition, stimulus shapes were simultaneously presented to both hands, and a comparison test shape presented to only one hand. A same/different forced choice response procedure was adopted. The results indicated that the left hand (right hemisphere) was more accurate than the right hand (left hemisphere) for fifth-grade children and adults, but no significant differences between hands were found for first- and third-grade children. The dichhaptic condition was a more difficult task than the single-hand condition, but similar laterality effects were found in both groups. An additional finding was that males made fewer errors than females. Thus, the results indicated that the right hemisphere becomes increasingly more specialized for tactile spatial ability with increasing age, and that there are sex differences, but these latter do not interact with hand performance.

The basic design of Galin et al. (1979) was replicated in the present study, but hand differences were explicitly examined. The single-hand uncrossed conditions of Flanery and Balling (1979) were also included in the design. As these investigators reported that similar laterality effects occurred in both single-hand and dichhaptic conditions, dichhaptic performance was not tested. Three different groups of subjects were tested: 6-year old children, 8-year old children, and adults. On the basis of Flanery and Balling's (1979) results, an increasing left-hand (right-hemisphere) accuracy with age was expected, starting with equal hand performance for the 6-year olds. It was also expected that as the tactile spatial task was possibly more difficult (involving spatial as well as tactile information processing) than the textural comparison task employed by Galin et al. (1979) an increasing degree of hemispheric integration in processing the information would be apparent across the age range investigated. Nevertheless, it could be expected from the Galin et al. (1979) findings that uncrossed performance would be superior to crossed performance, because in the latter case information loss during interhemispheric transfer could lead to less accurate responding. On the basis of recent reviews of spatial ability (e.g., McGee, 1979) it might also be expected that overall performance of males would be better than that of females. Furthermore, on the basis of findings suggesting less lateralization of functioning in females (Hutt, 1979; Witelson, 1977), one might expect a greater selective left-hand superiority to be displayed by males than by females.

An additional group of adult subjects was tested to allow for the possibility of the task being too easy for adults. Although Flanery and Balling (1979) did not report problems associated with ceiling effects in adult performance, data presented in their paper do indicate that adults achieved well above 75% accuracy. It could also be argued that a longer presentation time would increase the possibility of the information being fully disseminated throughout the two hemispheres of the adult brain, thus decreasing the likelihood of differences in hand performance occurring. In the current study, then, one group of adults had the same initial target shape presentation time as did the children (10 sec), whereas presentation time for the additional group of adult subjects was much shorter (5 sec).

The third group of subjects was deaf children, whose performance was compared with that of hearing children in order to investigate their possible abnormal development of brain organization. A finding of such an abnormality would support Luria's (1973) hypothesis that when one sensory system is deficient, functional interrelationships in the brain are affected. Similarly, Kelly and Tomlinson-Keasey (1977) postulated that combined processing of sight and sound results in the development of an organizationally different cognitive system from one developed primarily through visual input, as in the deaf (see Kelly (1978) for a review). Thus it was expected that the hearing children would show right-hemispheric specialization for processing the tactile spatial information requirements of the task. The deaf children, however, should not show such a left-hand (right-hemisphere) superiority, but equal performance across hands.

METHOD

Subjects

Three groups of right-handed subjects voluntarily participated in the study: hearing adults, hearing children, and deaf children. The adult group consisted of 32 undergraduate and postgraduate students (16 female and 16 male) in the age range 17 years 2 months to 46 years 5 months (M = 24 years 11 months). Adults were randomly assigned (with the restriction of equal numbers of males and females in each group) to two treatment groups: 10-sec presentation time (10-sec group) and 5-sec presentation time (5-sec group). Right-handedness of adults was assessed by performance on the Edinburgh Handedness Inventory (EHI: Oldfield, 1971; White & Ashton, 1976).[1]

The group of hearing children comprised 32 students (16 male and 16 female), with 16 at each of two ages: Older children, age range 7 years 7 months to 8 years 8 months (M = 8 years 4 months); and younger children, age range 5 years 10 months to 6 years 8 months (M = 6 years 2 months).

The group of deaf children comprised 16 students (8 male and 8 female) at a school for the Deaf. Because of a lack of eligible students in the 5- to 6-year-old age range, only one age group was tested in the deaf population. The age range of these older children was 8 years 11 months to 10 years 9 months (M = 9 years 10 months). These children were of average nonverbal intelligence, were prelingually deaf, and all except one child (whose average loss had improved to 65 dB following corrective middle ear surgery) had an average hearing loss of at least 90 dB. No child had any physical or mental handicap other than that directly associated with hearing loss. All children were learning to communicate through the "total communication" method—that is, using both sign and oral language. Right-handedness of all children was assessed by a three-item behavioral test.[2]

Materials

The testing apparatus was a box structure similar to that used by Witelson (1974, 1976). Subjects placed their hands through openings in a screen such that they were unable to see the stimulus shapes being touched. Twenty stimulus shapes were constructed following as closely as possible the descriptions given by Flanery and Balling (1979). These were 20 randomly generated nonsense forms, 10 with five angles and 10 with six angles. These forms were chosen on the assumption that they would not be amenable to linguistic coding which might facilitate left-hemisphere processing. All forms were cut from a sheet of Perspex 0.16 cm thick, and had a surface area of approximately 14.4 cm^2. Each form was mounted centrally on a styrofoam square, measuring 7.6 × 7.6 × 1.3 cm.

[1] A revised version (White & Ashton, 1976) of the EHI (Oldfield, 1971) was administered. This form has a score range of 18 to 90; the higher the score the higher the degree of right-hand preference. All adult subjects in the three studies reported scores between 75 and 90, indicating a high degree of right-hand preference.

[2] As the EHI is designed for adult administration, a short behavioral test is arguably the most effective means of assessing handedness in children. The three items are the most commonly used by a range of investigators (e.g., Annett, 1970; McFarland & Ashton, 1975). To pass the test, use of right hand for writing and using scissors and use of right hand or both hands for throwing the ball was required.

Procedure

The task involved blind palpation of an initial (target) shape by one hand, followed by blind palpation of a second (test) shape by the same (uncrossed condition) or other (crossed condition) hand. The test shape was either the same as or different from the first (target) shape, and this was the decision subjects had to make.

The subjects were given instructions as to the requirements of the task, and administered a minimum of four practice trials (with feedback) until it was clear that they fully understood their task. Instructions to deaf children were conveyed through a routine of sign language (Jeanes, Jeanes, Murkin, & Reynolds, 1972) and practical demonstration.

Before practice trials began subjects placed their hands (up to wrist level) through the box openings. Their hands remained in that position throughout the experiment except during rest intervals. In each trial, the experimenter lightly touched the back of the subject's left or right hand. Subjects then raised that hand so that the first (target) shape could be slipped under the hand into a fixed position. (Lines were drawn on the floor of the box structure to facilitate constant positioning of the shapes). Subjects immediately started to haptically explore the shape, and continued for a certain period (5 sec for the 5-sec group of adults, 10-sec for all other groups) after which the experimenter touched the subject's hand again and said "stop feeling." At that signal, subjects raised their fingers again and the shape was removed. The experimenter then touched subject's same (uncrossed) or other (crossed) hand, and the second (test) shape was placed into position. Subjects explored the test shape for up to 5 sec, by which time, if subjects had not already indicated their decision, the experimenter touched the subject's hand and said "decide now." This request also indicated that subjects should stop touching the shape. Initial overt verbal activity by the subject was eliminated by the use of hand signals: tapping the form with the index finger of the test hand meant "same," and waving the test hand from side to side meant "different." These responses were recorded. For each subject, target and distractor shapes were chosen randomly from the 20 stimulus shapes. Overall there were eight conditions, and the subjects were tested on each condition four times, giving 32 trials per subject.

In the experimental sessions with children three rest intervals were taken. During these times their handedness was assessed, or they talked with the experimenter. Adults had one rest interval, during which they completed the EHI.

RESULTS AND DISCUSSION

The primary data were accuracy scores, with a range of 0 to 4. Three approaches to the analysis of the data were taken. First, the data of the hearing younger and older children, and of the 10-sec group of adult subjects, were analyzed in an examination of developmental changes in performance on the task, as well as possible sex differences. This involved an age (younger children, older children, 10-sec adults) × sex (female, male) × presentation hand (left, right; L, R) × test hand (left, right; L, R) × test shape (same, different) mixed design repeated measures analysis of variance. Test shape was included as a factor because some studies (e.g., Barroso, 1976; Bradshaw, 1978; Patterson & Bradshaw, 1975) have suggested that the right hemisphere is specialized for making rapid, holistic matches ("same" stimuli processing) while the left hemisphere is specialized for detecting nonmatching features ("different" stimuli matching).

In the second approach, data from the two groups of adult subjects were analyzed to focus on the effect of *presentation time* (of the target shape) on lateralized performance on the task. This involved a presentation time (5-sec, 10-sec) × sex (female, male) × presentation hand (left, right) × test hand (left, right) × test shape (same, different) mixed design repeated measures analysis of variance.

In the third approach, the possible differential development of hemisphere specialization was examined by a *comparative analysis* of responses of the 8-year-old deaf and hearing children. This involved a group (hearing, deaf) × sex (female, male) × presentation hand (left, right) × test hand (left, right) × test shape (same, different) mixed design repeated measures analysis of variance.

Table 1 presents the summary data. Because no sex differences were found the data are collapsed over that variable.

A significant age effect in overall accuracy of response was found ($F(2, 42) = 16.5$, $MS_e = 1.25$, $p < .01$), with adults giving appreciably more accurate responses than older ($F(1, 42) = 15.31$, $MS_e = 1.25$, $p < .01$), and younger children ($F(1, 42) = 31.25$, $MS_e = 1.25$, $p < .01$), although there was no difference between the accuracy scores of older and younger children ($F(1, 42) = 2.81$, $MS_e = 1.25$, $p > .05$). There was also a suggestive age × presentation hand interaction ($F(2, 42) = 3.44$, $MS_e = 0.85$, $p < .05$). An examination of this interaction revealed the interesting finding that although the accuracy score for the left hand was greater than for the right in older children ($F(1, 42) = 5.75$, $MS_e = 0.85$, $p < .02$), the difference was not significant for younger children ($F(1, 42) = 3.32$, $MS_e = 0.85$, $p > .05$).

The other significant finding was a four-way age × presentation hand × test hand × test shape interaction ($F(2, 42) = 9.29$, $MS_e = 0.55$, $p < .01$). Examination of the same hands (presentation and test) conditions revealed that although the LL (left, left) accuracy score is higher than the RR (right, right) accuracy score for the older children ($F(1, 42) =$

TABLE 1

MEAN ACCURACY SCORES AND STANDARD DEVIATIONS (IN PARENTHESES) ON THE SAME AND DIFFERENT TEST SHAPES FOR EACH GROUP OF SUBJECTS (N = 16 PER GROUP, DATA FOR EACH SEX COMBINED)

	Uncrossed				Crossed			
	LL		RR		LR		RL	
Age and condition	Same	Different	Same	Different	Same	Different	Same	Different
10-Sec adults	3.75	3.37	2.81	3.62	3.06	3.69	3.31	3.44
	(.58)	(.81)	(.65)	(.62)	(.93)	(.60)	(.70)	(.63)
5-Sec adults	3.31	3.75	3.06	3.62	3.00	3.62	3.62	3.25
	(.70)	(.45)	(1.06)	(.50)	(1.09)	(.72)	(.62)	(.77)
Older children	3.25	3.19	2.37	3.31	2.62	2.57	3.12	1.94
	(1.00)	(.91)	(1.20)	(.87)	(1.15)	(1.29)	(.88)	(.85)
Younger children	2.31	3.25	2.5	3	1.87	3.06	2.12	2.62
	(.60)	(1.18)	(1.50)	(1.03)	(1.5)	(1.00)	(1.54)	(1.36)
Deaf children	3.31	3.50	2.94	3.5	3.06	2.81	3.44	3.06
	(.79)	(.63)	(.93)	(.89)	(1.12)	(.98)	(.51)	(.93)

9.17, $MS_e = 0.82$, $p < .01$), the difference for the younger children was not significant ($F(1, 42) = 2.73$, $MS_e = 0.82$, $p > .05$). These results reflect, to a certain extent, the age × presentation hand effect discussed earlier, with adults tending to show opposite hand performance to that of children, with the hand difference reaching significance only for the older children.

Examination of the age × test shape interaction showed that the younger children responded well with the different shapes, but rather poorly with the same test shapes. This effect is reflected in the LL ($F(1, 42) = 14.55$, $MS_e = 0.55$, $p < .01$) and RL ($F(1, 42) = 25.08$, $MS_e = 0.55$, $p < .01$) conditions. A peculiar test shape effect is found in the RR condition, with the accuracy of older children's responses to different test shapes being significantly lower than that to same test shapes ($F(1, 42) = 20.51$, $MS_e = 0.55$, $p < .01$).

In a partial replication of the Galin et al. (1979) developmental integration findings, a number of planned F tests were conducted comparing performance in crossed and uncrossed conditions at each age level. None of the differences was significant, which contrasts with the findings of Galin et al. (1979).

In summary, then, a clear left-hand superiority was found in the performance of the older children, indicative of right-hemisphere superiority for tactile spatial processing. Results were less clear for the younger children, although left-hand superiority was apparent, overall low accuracy scores indicated that the task may have been slightly beyond their normal capabilities. Some sex differences occurred in the youngest age group in the crossed conditions; females appeared less capable of correctly discriminating "same" test shapes. No difference in accuracy between averaged crossed and uncrossed conditions occurred, at any age level, and it was found that the RR accuracy was *less* than the average crossed conditions accuracy for both older and younger children. With respect to adult performance, the right hand appeared to excel. This may have been a function of the ease of the task for the 10-sec group of adults, as overall accuracy was high.

Presentation Time Analysis

The main effect for presentation time was not significant ($F(1, 28) = 0.03$, $MS_e = 1.06$, $p > .05$), indicating that adult subjects with only 5 sec to explore the initial target shape performed no better or no worse than did subjects given 10 sec to explore the shape. Some of the higher-order interactions suggested that in the uncrossed conditions presentation time was an important factor, with the expected left-hand superiority emerging in the shorter time condition. The marginal levels of significance achieved, however, preclude further discussion at this point.

Comparative Analysis of Deaf and Hearing Individuals

Deaf children performed significantly better than did hearing children ($F(1, 28) = 7.02$, $MS_e = 1.18$, $p < .02$), which was not expected. Overall accuracy of the left presentation hand was significantly higher than that of the right presentation hand ($F(1, 28) = 5.76$, $MS_e = 0.88$, $p < .02$), but accuracy of the left test hand was not significantly higher than that of the right test hand ($F(1, 28) = 3.80$, $MS_e = 19.47$, $p = .06$). The main significant difference between pairs of means were LL and RR ($F(1, 28) = 7.80$, $MS_e = 0.96$, $p < .01$).

There was a significant group × presentation hand × test shape interaction ($F(1, 28) = 9.139$, $MS_e = 0.62$, $p < .01$) and a significant presentation hand × test hand × test shape interaction ($F(1, 28) = 6.724$, $MS_e = 0.59$, $p < .02$). These are possibly best examined in the light of the significant group × presentation hand × test hand × test shape interaction ($F(1, 28) = 6.724$, $MS_e = 0.59$, $p < .02$). As stated above, overall performance of deaf children was better than that of hearing children. One of the major differences between hearing and deaf children is in the RR condition, where, as discussed in the developmental analysis, the performance of hearing 8-year old children on different test shapes drops significantly. The difference is not apparent for the deaf children. Indeed, overall performance in the RR condition was not significantly different from that in the LL condition. Thus, deaf children do not show the expected LL superiority. Looking at the crossed conditions, performance of deaf children was actually better in the crossed conditions than in the uncrossed conditions ($F(7, 28) = 29.18$, $MS_e = 0.96$, $p < .01$); although there was no appreciable difference for hearing children.

In summary, the current data indicated that hearing children showed the expected left-hand superiority (as discussed in the *developmental* results) and the deaf children showed the expected lack of hand differences. The reason for the latter finding is not that clear, however, because deaf children's overall performance was better than that of hearing children; thus a ceiling effect may have been operating. The finding that the average crossed conditions accuracy score was higher than the uncrossed conditions score for the deaf children is puzzling, and is contrary to expectations based on previous hemispheric and integration studies (e.g., Galin et al., 1979).

GENERAL DISCUSSION

The major hypotheses posed in this study were basically supported by the data. Right hemispheric specialization for the tactile spatial information processing requirements of the task was more evident in older children than in younger children (a floor effect may have been operative in the younger children's performance). A developmental factor for integration was not found, and crossed condition performance was found to be greater than RR performance in younger and older children. Examination of sex effects suggested that the degree of hemispheric integration was less for 6-year-old females than for 6-year-old males, although there were no overall differences in accuracy. Analyses of the two adult groups' data suggested that the 5-sec presentation time procedures may more adequately index hemispheric specialization than 10-sec presentation time procedures, but a parametric study needs running on this topic. Overall performance of deaf children was superior to that of hearing children, although hemispheric specialization was more evident in hearing children's performance than in deaf children's performance.

The present results elucidate the nature of the interaction between hemispheric specialization for, and hemispheric integration of, information processing. In particular, accuracy score data indicated that hemispheric specialization is an important mediating variable in the investigation of hemispheric integration. Contrary to Galin et al. (1979), significant differences between left and right uncrossed conditions (LL, RR) were found for accuracy score data, and accuracy in the uncrossed right condition (RR) was often less than that in the crossed conditions (RL and LR). Both of these findings suggest that a hemisphere's specialization for processing particular types of information may have differential effects on performance in crossed and uncrossed conditions. This was not suggested by Galin et al. (1979), although they did find that errors in the RL condition were greater than that in the LR condition. The differences between these two sets of findings may be attributable to the different stimulus materials used, or to the different response procedures used. In particular Galin et al. (1979) used an unlimited response time procedure, which may have enabled considerable dissemination of the tactile spatial information throughout the brain, thus decreasing the possibility of differential hand performance.

Very few sex differences were found in this study, and they do not merit further discussion, being probably merely a "bonus factor" (Fairweather, 1976).

The great overall accuracy in performance by deaf children as compared to older hearing children was not expected. Few researchers in the field would argue that an individual suffering a deficit of experience in one sensory modality succeeds in compensating for the deficit by increasing abilities associated with other sensory modalities. Instead, it is thought by many (e.g., Luria, 1973; Jones, 1972) that a deficit in processing ability of information from one sensory modality affects cognitive processing as a whole, such that abilities in other areas rarely reach normal standards, let alone surpass such standards. It does appear, however, from the results of this study that deaf children are superior in tactile spatial processing to hearing children. Some studies have, in fact, reported a superior performance by deaf children (e.g., Ross, Pergament, & Anisfeld, 1979; Kelly & Tomlinson-Keasey, 1977); these differences are usually deemphasized and attempted explanations are rare. No hemispheric specialization effects were apparent in deaf children, however, and they performed better in crossed than in uncrossed conditions. These effects may have been due to some kind of ceiling effect in performance, although none of the deaf subjects was able to respond with 100% accuracy. It may be reasonable to surmise that the greater ability of the deaf children on the task may be associated with tactile spatial information being just as effectively processed by the left hemisphere as by the right hemisphere. This development of spatial information processing ability in the left hemisphere may be associated with the spatial aspects of the deaf person's communication system (Neville, 1976) or with an increased compensatory ability of the left hemisphere to process visual/spatial in lieu of auditory/sequential information.

Finally, the problem of ceiling effects needs to be mentioned. Thus one reason why lateralization of ability in adults was not clearly demonstrated may quite possibly be the result of the task being too easy; a ceiling effect occurred. Similarly with the deaf children, their overall performance was so good that subtle laterality effects may have been masked. One variable that can be manipulated without modifying the actual stimulus material (which would introduce problems of interpretation) is that of presentation time. Shortening this variable would make the task more difficult without changing its nature. There was a suggestion in the results for the 5- and 10-sec presentation time conditions with adults that the expected left-hand superiority was beginning to emerge under the shorter time condition. A parametric examination of this variable is an obvious candidate for future research.

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